# Data fusion : a conceptual approach for an efficient exploitation of remote sensing images

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# DATA FUSION: A CONCEPTUAL APPROACH FOR AN EFFICIENT EXPLOITATION OF REMOTE SENSING IMAGES

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ABSTRACT: The need for a definition of the concept of data fusion is established. Already published definitions are discussed. A new definition of the data fusion is proposed, which allows to set up a conceptual approach to the fusion of Earth observation data by putting an emphasis on the framework and on the fundamentals in remote sensing underlying data fusion. Further definitions are given which describe the information intervening in any problem of data fusion. Finally the property of alignment of the information to be fused is discussed.

## 1. INTRODUCTION

Data fusion is a new term which describes an approach to information extraction spontaneously adopted in several domains where more and more information are becoming available. It results mostly from the military needs. It has been previously termed co-operative sensors, co-operative detectors, among others. The quantity of information available to describe our environment increases rapidly. Archives are growing, as well as the number of space missions devoted to Earth observation. Data fusion is therefore becoming increasingly relevant in remote sensing. However the mathematical operations by themselves are not new in remote sensing. For example, classification procedures are performed for more than twenty years, and are obviously relevant to data fusion (see e.g., Mangolini 1994; Pohl 1996). It is generally correct to assume that improvements in terms of classification error probability, rejection rate, and interpretation robustness, can only be achieved at the expenses of additional independent data delivered by more separate sensors. Data fusion allows to formalise the combination of these measurements, as well as to monitor the quality of information in the course of the fusion process.

The concept of data fusion is easy to understand. However its exact meaning varies from one scientist to another. Several words have appeared, such as merging, combination, synergy, integration, ... All of them appeal more or less to the same concept but are however felt differently. There is also a fashion. Several times, the word « fusion » is used while « classification » would be more appropriate, given the contents of the publication.

## 2. THE NEED FOR TERMS OF REFERENCE IN REMOTE SENSING

There is a need for terms of reference in the remote sensing community. It has been strongly expressed in several meetings, including those organised by EARSeL or SEE (see e.g., Van Genderen, Pohl 1994; Wald 1997). The establishment of a lexicon or terms of reference permits to the scientific community to express the same ideas using the same words. Moreover it is a *sine qua non* condition to set up clearly the concept of data fusion and the associated formal framework. Such a framework is mandatory for a better understanding of data fusion fundamentals and of its properties. It allows a better description and formalisation of the potentials of synergy between the remote sensing data, and accordingly, a better exploitation of these data.

The present communication aims at providing the basis for this framework. It should be noted that this is not the only attempt to set up definitions in data fusion. The remote sensing community should

not establish terms which are also used elsewhere with different meanings. Therefore, whenever possible, definitions were adopted which are already widely used in the broad scientific community, especially that dealing with information. Examples of such terms are image, features, symbols, etc.
Several lexicons have been already set up. They have all been established in the framework of the Defence domain (e.g., U.S. Department of Defence 1991; DSTO 1994). Most of the terms are part of the military jargon. They express needs of the Defence which may be partly similar to those in other domains where crisis occur, such as the management of a power plant. However it is not easy to translate military terms in meaningful words for the scientific community dealing with Earth observation. Though the European Space Agency has recently adopted the terms « tactical » and « strategic » for the new SAR instrument aboard Envisat, it is difficult to find equivalent words in civil remote sensing for the words « threat », « enemy », « engagement », « battlefield » found in the published lexicons. It can be done in some cases. Furthermore the needs of the Defence are associated to specific time and space scales, which are not covering all those dealt with in Earth observation. For example, climatology is not a word used in the military domain. Using these military lexicons would imply a refinement of the military terms to expand their meaning, with a reference to the time-space scales. It is concluded that using an existing lexicon is not straightforward, and that a new one is required to tackle the specific needs of our community. However we should benefit from these previous works as much as possible, and, whenever possible, we should use either the terms already adopted or global architectures, etc.
The present communication summarises the discussions held within EARSeL and SEE since the first conference on Earth data fusion held in Cannes, France, in February 1996. It proposes some definitions, which are open to comments. The goal is to achieve a consensus on this lexicon, during the meeting of the Special Group of Interest following this second international conference.

## 3. DEFINITION OF DATA FUSION

Data fusion means a very wide domain. It gathers a large number of methods and mathematical tools, ranging from spectral analysis to plausibility theory. Fusion is not specific to a theme or an application. On the contrary the tools used in a fusion process for a specific application may be tailored to that case. It is very difficult to provide a precise definition of data fusion. This large domain cannot be simply defined by restricting it, for example, to specific wavelengths, or specific acquisition means, or specific applications. Fusion process may call upon so many different mathematical tools that it is impossible to define fusion by these tools. For example, both the simple sum of two images acquired by two different sensors, and the more sophisticated encrustation of one image into the other using the multiresolution analysis (Wald, Ranchin 1995), are considered as fusion processes. Both implies at least a preliminary geocoding of the data. On the contrary, a classification technique based upon a sophisticated neural network does not constitute itself a fusion process if it applies to spectral imagery acquired by a single sensor (e.g., Landsat TM). Obviously the concept of data fusion is useful when at least two different sensors are at stake.
Several definitions have already been proposed. Van Genderen, Pohl (1994) proposed « image fusion is the combination of two or more different images to form a new image by using a certain algorithm ». This definition is restricted to images. Mangolini (1994) extends data fusion to information in general and also refers to quality. He defines data fusion as a « set of methods, tools and means using data coming from various sources of different nature, in order to increase the quality (in a broad sense) of the requested information ». However, these definitions put the accent on the methods. They contain the large diversity of tools, but are restricted to these. Hall, Llinas (1997) also refer to information quality in their definition but still focus on the methods: « data fusion techniques combine data from multiple sensors, and related information from associated databases, to achieve

improved accuracies and more specific inferences that could be achieved by the use of a single sensor alone ».

A working group of the U.S. Department of Defence (1991) stated that « data fusion is a multilevel, multifaceted process dealing with the automatic detection, association, correlation, estimation, and combination of data and information from multiple sources ». Klein (1993) slightly refines the definition as a « multilevel, multifaceted process dealing with the automatic detection, association, correlation, estimation, and combination of data and information from single and multiple sources ». This definition is more general with respect to the types of information than can be combined (multilevel process). However it does not mention quality, and may be restrictive when listing actions that can be performed onto the information. Li *et al.* (1995) wrote « fusion refers to the combination of a group of sensors with the objective of producing a single signal of greater quality and reliability ». Quality and reliability are referred to, but there is no reference to concepts. Furthermore it is restricted to sensors and signal.

In data fusion, information may be of various nature: it ranges from measurements to verbal reports. Some data cannot be quantified; their accuracy and reliability may be difficult to assess. In Earth observation domain, one may use some features held in a geographical information system to help in classifying multispectral images provided by several sensors. In this particular case, some data are measurements of energy, and others may be symbols.

Accordingly the definition for data fusion should not be restricted to data output from sensors (signal). Opposite to most of the published definitions, it should not be restricted to methods and techniques or architectures of systems, since we aim at setting up a conceptual framework for data fusion. I suggest the following definition: « data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different sources, in order to obtain information of greater quality ».

This definition is clearly putting an emphasis on the framework and on the fundamentals in remote sensing underlying data fusion instead of on the tools and means themselves, as is done usually. The latter have obviously strong importance but they are only means not principles. Secondly it is putting also an emphasis on the quality. This is certainly the aspect missing in most of the literature about data fusion, but one of the most delicate. Here quality has not a very specific meaning. It is a generic word denoting that the resulting information is more satisfactory for the « customer » than before performing the fusion processes. For example, a better quality may be an increase in accuracy, or in the production of a more relevant information.

Using this definition, any processing of images acquired by the same sensor is not relevant to the data fusion domain, such as classification of multispectral imagery (e.g., Landsat TM only, or SPOT XS only), or computation of the NDVI (normalised difference vegetation index), or atmospheric correction of spectral bands using other bands of the same sensor (e.g., CZCS, SeaWiFS, MeRIS, AVHRR, ATSR). Any processing of time-series of data acquired by the same sensor is not a fusion process. For the sake of simplicity, the special case of large time-series where different copies of the same sensor, such as Meteosat, are involved should be let out the fusion domain.

## 4. OTHER DEFINITIONS

I suggest to use the terms merging, combination in a different meaning than fusion. These two terms will be considered as equivalent. They define any process that implies a mathematical operation performed on at least two sets of information. The words merging and combination denote operations while fusion denotes a framework. It follows that merging or combination is not entirely included in data fusion and vice-versa. Data fusion calls upon operations for merging different sources of information, but merging can take place out of the fusion framework. For example, the computation of the NDVI is a combination of spectral bands but is not a fusion process.

We can see here the advantage of the proposed definition for fusion. The accent put on the framework permits a clear distinction between fusion and merging or combination.

Another domain pertains to data fusion: data assimilation or optimal control. Data assimilation deals with the inclusion of measured data into numerical models for the forecasting or analysis of the behaviour of a system. A well-known example of a mathematical technique used in data assimilation is the Kalman filtering. Data assimilation is daily used for weather forecasting.

Fusion may be performed at different levels: at measurements level, at attribute level, and at rule or decision level. These terms as well as others related to information are defined in the following. These definitions are those used in information theory and have been found in several publications (e.g., Bijaoui 1981; Lillesand, Kiefer 1994; Kanal, Rosenfeld 1981; Tou, Gonzalez 1974).

Measurements are primarily the outputs of a sensor. It is also called signal, or image in the 2-D case. The elementary support of the measurement is a pixel in the case of an image, and is called a sample in the general case. By extension, measurement denotes the raw information. For example, a verbal report is a piece of raw information, and may be considered as a signal. In remote sensing, in the visible range, the measurements are digital numbers that can be converted into radiances once the calibration operations performed. If corrections for the sun angle are applied, one may get reflectances which are still considered as signal.

An object is defined by its properties, e.g., its colour, its materials, its shapes, its neighbourhood, etc. It can be a field, a building, the edge of a road, a cloud, an oceanic eddy, etc. For example, if a classification has been performed onto a multispectral image, the pixels belonging to the same class can be spatially aggregated. This results into a map of objects having a spatial extension of several pixels. By extension, a pixel may be considered as an object.

An attribute is a property of an object. For example, the classification of a multispectral image allocates a class to each pixel; this class is an attribute of the pixel. The equivalent terms label, category or taxon are also used in classification. Another well-known example is the spatial context of a pixel, computed by local variance, or structure function or any spatial operator. This operation can be extended to time context in the case of time-series of measurements. Equivalent terms are local variability, local fluctuations, spatial or time texture, or pattern. By extension, any information extracted from an image (or mono-dimensional signal) is an attribute for the pixel or the object. The aggregation of measurements made for each of the elements of the object (for example, the pixels or samples constituting the object), such as the mean value, is an attribute. Some authors call mathematical attribute such attribute deriving from statistical operations on measurements. Feature is equivalent to attribute.

The properties of an object constitute the state vector of this object. This state vector describes the object, preferably in an unique way. The state vector is also called feature vector, or attribute vector. The common property of the elements of the state vector is that they all describe the same object. If the object is a pixel (or a sample), the state vector may contain the measurements as well as the attributes extracted from the processing of the measurements.

Works in pattern recognition in has drawn an analogy with the syntax of a language. Terms of higher semantic content have been defined, such as rules and decisions. Rules, like the syntax rules in language, define relationships between objects and their state vectors. They are often expressed in elaborated language. Known examples of such rules are those used in artificial intelligence and expert-systems. Decisions are actually rules of higher content which apply on a set of rules, objects and state vectors. Decision may result from the fusion of rules. Fusion may also be performed on decisions.

Usually, fusion of measurements results into attributes, and fusion of attributes into decisions. It is not always straightforward. Let take the case of the ARSIS concept (Mangolini *et al.* 1993; Ranchin *et al.* 1996) which increases the spatial resolution of a multispectral image given another image of a better resolution not necessarily acquired in the same spectral bands. It intends to simulate what would observed a multispectral sensor having a better spatial resolution. Accordingly, it simulates measurements through a fusion process and inference models. However, the results are not measurements, and are attributes. Since they are obtained at each pixel, and since the calibration is taken into account during the process, these attributes are similar to actual measurements.

A fusion system can be a very complicated system. It is composed of sources of information, of means of acquisition of this information, of communications for the exchange of information, of intelligence to process the information and to issue information of higher content. The issues involved may be separated in topological and processing issues. Despite the interconnection between both issues in an integrated fusion system design, they can be decoupled from each other in order to facilitate the development of a systematic methodology of analysis and synthesis of a fusion system (Thomopoulos 1990, 1991).

The topological issues address the problem of spatial distribution of sensors, the communication network and issues for the exchange of information, the availability and reliability of information at the time of the fusion. The cost of acquiring the information may also be relevant to the topological issues. In remote sensing, these issues are partly adressed by the space agencies and by the image vendors. It is also partly adressed by the customer, given its objectives and constraints, including the financial budget.

The processing issues address the question of how to fuse the data, *i.e.* select the proper measurements, determine the relevance of the data to the objectives, select the fusion methods and architectures, once the data are available.

## 5. THE PROPERTY OF ALIGNMENT

Several problems are to be solved prior to any process of fusion (see e.g., Castagnas 1995, Pau 1988). The information entering a fusion process should present several properties. They deal with either the selection of the representation space and the level of fusion, or with the processing to be applied onto the data.

A common co-ordinate system (e.g., geographical space and time) should be found in which the sources data can be represented. This is called alignment, or conditioning, or positional data fusion. For example, geocoding the images is part of the alignment problem. Then the images are superimposable and mathematical operations can be performed at each pixel.

The alignment problem is difficult and according to some authors (see e.g., Thomopoulos 1991; DSTO 1994), it differentiates data fusion from data concatenation. Data concatenation is accomplished easily and straightforward by juxtaposing all the data into the state vector, hence augmenting it. These data should be homogeneous. An example is given by a time-series of images from the geostationary satellite Meteosat. The raw data are processed by Eumetsat, and are spatially superimposable once delivered to the customer. In that case, at each pixel, one can define a state vector by the concatenation of all the observations made at this pixel in the period under concern.

Data fusion requires conversion of the data into a common co-ordinate frame before concatenation. Alignment should provide a general frame of referencing that can applied to homogeneous (commensurate) as well as heterogeneous (non-commensurate) data. This is a difficult problem, and there is no general theory. Even in the simple case of measurements of radiances, which are comensurate, it may still be not straightforward. Though having the same space reference, two sources may not refer to the same object (landscape). In the Meteosat case, the water vapour channel does not provide any information on the ground, while the visible and infrared channels do. Another example in oceanography is the fusion of observations of sea surface temperature, which are relevant to the very surface of the ocean, and of ocean colour, which are depth-integrated. Data to be fused need to be relevant to the objectives of fusion process. Then these data can be associated or concatenated into the state vector of the studied object (landscape).

This concept is extended to a wider reference space (representation space) which also includes standardisation of units, calibration of sensors and atmospheric corrections, etc., if necessary.

The alignment problem calls upon physics, and is certainly the probelm in data fusion which is the most relevant to the concerns of the remote sensing community.

## 6. CONCLUSION

A new definition of the data fusion has been proposed which better fits the remote sensing domain. Data fusion should be seen as a framework, and not only as collection of tools and means. This definition emphasises the concepts and the fundamentals in remote sensing. It also permits a clear distinction between data fusion and data merging or combination.

The problem of alignment of the information to be fused is very difficult to tackle. It is a pre-requisite to any fusion process and should be considered with great care. The remote sensing community may play a role in that domain since it has a great experience in both the physics involved, including sensors, and the mathematical operations of sampling.

On the opposite way, the introduction of the concept of data fusion into the remote sensing domain should rise the awareness of our colleagues on the whole chain ranging from the sensor to the decision, including the management, assessment and control of the quality of the information.

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